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CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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November 6, 2012

Cahier n° 2012-29

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Abstract

In liberalized network industries, entrants can either compete for service using the existing infrastructure (access) or deploy their own infrastructure capacity (bypass). In this paper, we demonstrate that, under the threat of bypass, the access price set by an unregulated and vertically integrated incumbent is compatible with productive efficiency. This means that the entrant bypasses the existing infrastructure only if it can produces the network input more efficiently. We show that the incumbent lowers the access price compared to the ex-post efficient level to strategically deter inefficient bypass by the entrant. Accordingly, from a productive efficiency point of view, there is no need to regulate access prices when the entrant has the option to bypass. Despite that, we show that restricting the possibilities of access might be profitable for consumers and welfare because competition is fiercer under bypass.

Keywords: Make-or-buy, Access price, Bypass
JEL Codes: L13, L51

*The authors are grateful to C. Cambini, F. Etro, K. Mizuno and conference participants at the IIOC (Washington) and EARIE (Roma) for helpful comments.

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1 Introduction

In liberalized network industries, competitors of the historical operator have the choice between two modes of competition: service-based and facility-based competition. In the former case, competing firms offer retail products and services using the incumbent's installed infrastructure for which they pay an access fee (the 'buy' or the 'access' option). In the latter case, firms develop their own infrastructure to compete on the retail market (the 'make' or the 'bypass' option). This can be illustrated by the broadband service market where the two modes of competition coexist. In the countries where access to the incumbent's DSL network is mandatory, rival firms can supply services on the incumbent's network. Alternatively, firm can develop their own platform (cable TV network, wireless) to provide broadband services to consumers.

In this paper, we revisit the issue of make-or-buy by analyzing the strategic use of the access price in order to deter bypass by the incoming firm. By analogy with the literature on entry deterrence (Tirole, 1988) we identify three régimes: accommodated bypass, prevented bypass and blocked bypass.[1] We show that the incumbent accommodates bypass only if the entrant is more cost effective. Hence, even when the incumbent strategically sets the access charge to deter bypass, the make-or-buy decision of the entrant is technologically efficient. However, the limit access price chosen to deter bypass is inefficiently high resulting in higher retail prices despite lower production costs. Hence, in the parameter region where bypass is prevented, the regulator may prefer to restrict access in order to enhance competition between the two providers. Furthermore, any local change in the access price raises consumer surplus, either because it induces a change in the make-or-buy decision of the entrant or because it reduces the access price.

In order to understand our results, notice that the intensity of retail price competition depends on the technological choice made by the entrant. If the entrant buys access to the existing infrastructure, the incumbent has an opportunity cost of decreasing its retail price corresponding to the lost income on the access product (Sappington, 2005). Hence, the aggressiveness of the incumbent at the price setting stage is inversely related to the price cost margin on the access product. The choice of a technology, access or bypass, by the entrant is not only driven by the relative cost of the two technologies but also by the intensity of competition on the retail market.

[1] Bloch and Gautier (2008) made the same distinction for a fully-regulated market.

To deter bypass, the incumbent must set an access price at a level that guarantee a higher profit for the entrant when it chooses service-based competition compared to infrastructure-based competition. This requires lowering the access price below the ex-post efficient level. But a lower access price increases the firms' aggressiveness at the price competition stage. Indeed, the entrant has a lower production cost (the access price) and the incumbent has a lower opportunity cost making price competition fiercer. In this paper, we demonstrate that when the entrant is more cost effective than the incumbent, the bypass deterrence strategy requires selling access at losses which intensifies retail price competition and lead to lower profits than the bypass option. For that reason, the incumbent does not find profitable to deter bypass when its competitor is more efficient. Conversely, when the entrant is less cost effective, bypass can be prevented with an access price above the entrant's cost and retail price competition is thus soften. We thus have a paradoxical situation: Under the threat of bypass, an unregulated access price induces an efficient make-or-buy choice by the entrant but it leads to higher retail prices for the consumers.

For that reason, there is still room for market regulation. Indeed, policies that aim at promoting mandatory access to the incumbent's infrastructure might not be the most appropriate, particularly when a possibility of bypass exists. The bypass deterrence strategy benefits to the firms at the expense of the consumers. Restricting the possibilities of access may be welfare improving even if it increases the production costs. Mandatory access has been criticized on the grounds that it deters investment in alternative infrastructures.[2] In this paper, we show that price competition is fiercer under inter-platform competition compared to service-based competition. Mandatory access may thus be detrimental both in the short-run (higher retail prices) and the long-run (lower investments).

We now situate our contribution with respect to the existing literature. The question of efficient make-or-buy decision has received a lot of attention both from a static and a dynamic point of view. In dynamic models, facility-based competition is often considered as a long-term objective. The question then is to know whether allowing for service-based competition accelerates the development of facility based competition (the so-called

[2]In an international study using a sample of OECD countries, Bouckaert *et. al* (2010) found that a more important market share of service-based competitors on the DSL platforms is associated with lower rates of broadband penetration. Accordingly, mandatory access to the incumbent DSL networks negatively affect the incentives to invest in alternative broadband networks. See also Cambini and Jiang (2009) for a detailed survey on this issue.

step-stone effect identified by Cave and Vogelsang, 2003) or delays the installation of new infrastructure (Bourreau and Doğan, 2005). For Cave and Vogelsang (2003), service-based competition allows new comers in the industry to invest progressively in their own infrastructure, first in replicable assets (e.g. long-distance conveyance facility) then in less replicable ones (e.g. local loop). When there are ladders of investment, leasing part of the existing infrastructure is then essential for the development of facility-based competition. Accordingly, a low access price accelerates the deployment of alternative infrastructures.[3] For Bourreau and Doğan (2005), allowing for access delays investment in competing infrastructures because the cost of a new infrastructure includes an opportunity cost equals to the profit realized under service-based competition (an effect that is similar to the replacement effect in innovation races). Following that, a lower access price increases the opportunity cost of bypass and should delay further infrastructure building.

In a static setting, Sappington (2005) demonstrates the irrelevance of the access price for the choice between service- and facility-based competition and he shows that the most efficient mode of competition always emerges in an unregulated market. The entrant develops its own infrastructure only if it can provide the network input more efficiently than the incumbent. Sappington's argument is constructed using an Hoteling model with a fully-covered market. Gayle and Weisman (2007) demonstrate that, in more general setting, the access price matters for the choice of a mode of competition. Thereby, setting the access price appropriately is of prime importance to induce efficient technological choices. Mandy (2009) identifies a set of access prices that induce productive efficiency among which he recommends pricing access at the *entrant's* marginal cost. With such a price, the entrant bypass the incumbent's network only when it is more cost effective.

Our work is directly connected to the three above mentioned paper. We consider, as in Gayle and Weisman (2007), models where the access price is relevant for the choice between access and bypass, namely price competition with differentiated products.[4] In these set-ups, we analyze, as Sappington (2005) the question of productive efficiency or, differently, whether the access prices identified by Mandy (2009) emerge from an unregulated market scenario and we conclude that productive efficiency is achieved for non-regulated access prices.

[3]For Avenali *et al.*, (2009), the access charge should rise over time. Early service-based entry is then profitable and the competitors have the time and the incentives to progressively switch to facility-based competition.

[4]Our results can be extended to the Cournot competition case.

The rest of the paper is organized as follows. We introduce the model in Section 2, and discuss our basic analysis of strategic bypass deterrence in Section 3. Section 4 is devoted to an illustrative linear example, and Section 5 to robustness checks and extensions of the model. We give conclusions and directions for future research in Section 6.

2 The model

We consider a model of price competition between two firms: a vertically integrated incumbent, firm 1, and a competitor, firm 2. To produce for the retail market, firms need a network input. Firm 1 has an installed network and it can produce one unit of network input at unit cost c_1. Firm 2 has no installed network. To produce, it has two options: *access* or *bypass*. The entrant either buys access to the the firm 1's network at unit price w or it installs its own network infrastructure and produces the network input at unit cost c_2. The quality of the good produced by firm 2 is independent of the technology chosen to produce it. We assume that all other costs are normalized to zero. Results would not be changed if the incumbent has to support a fixed network cost f_1, as it would be sunk anyway and we will consider in section 5, the case in which installing the network involves a fixed cost f_2 for the entrant.

In the retail market, the demand for product supplied by firm $i = 1, 2$ at prices (p_i, p_j) is given by $x_i(p_i, p_j)$. Products are differentiated, and the products are substitutes so that the demand functions satisfy the natural conditions: $\frac{\partial x_i}{\partial p_i} < 0$, $\frac{\partial x_i}{\partial p_j} > 0$ and there exists $\overline{p}$ such that $x_i(p_i, p_j) = 0$ for all p_j and all $p_i > \overline{p}$. In addition, we will assume that firms never choose to set a price $p_i > \overline{p}$, and that the access charge w is bounded above by $\overline{p}$.

When firm 2 chooses the access option, the incumbent sells two products: the retail good 1 at price p_1 and access to its network at price w. Both goods are produced at unit cost c_1 and the firms' profits in the access regime are given by:

$$\begin{aligned} \pi_1^a(p_1, p_2, w) &= (p_1 - c_1)x_1(p_1, p_2) + (w - c_1)x_2(p_1, p_2), & (1) \\ \pi_2^a(p_1, p_2, w) &= (p_2 - w)x_2(p_1, p_2). & (2) \end{aligned}$$

When firm 2 chooses the bypass option, each firm sells a single product and the profits are:

$$\begin{aligned} \pi_1^b(p_1, p_2) &= (p_1 - c_1)x_1(p_1, p_2), & (3) \\ \pi_2^b(p_1, p_2) &= (p_2 - c_2)x_2(p_1, p_2). & (4) \end{aligned}$$

We make the following assumptions on the parameters of the model.

Assumption 1 *The demand functions, access and bypass profit functions satisfy the following conditions:*

$$\frac{\partial^2 \pi_i^a}{\partial p_i^2} < -\frac{\partial^2 \pi_i^a}{\partial p_i \partial p_j} < 0, \frac{\partial^2 \pi_i^b}{\partial p_i^2} < -\frac{\partial^2 \pi_i^b}{\partial p_i \partial p_j} < 0,$$

and

$$-(\frac{\partial x_2}{\partial p_1})^2 \frac{\partial^2 \pi_1^a}{\partial p_1^2} - \frac{\partial x_2}{\partial p_1}\frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2} + \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1^2}\frac{\partial^2 \pi_2^a}{\partial p_2^2} - \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2} < 0.$$

The first part of Assumption 1 guarantees that profit functions are concave in prices, that best response functions are increasing, and that the slopes of the best response functions are everywhere smaller than one. These assumptions are needed to prove existence and uniqueness of equilibrium prices. The second part Assumption 1 is needed to verify that the profit of the entrant is always decreasing in the access price w. While this Assumption corresponds to the "natural" case, it need not always be satisfied and only holds when the direct effect on prices, as measured by the second derivative $-\frac{\partial^2 \pi_1^a}{\partial p_1^2}$ is sufficiently high with respect to the indirect effect measured by the cross derivative $\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2}$.[5]

We finally describe the timing of the model. As in classical models of entry deterrence, we suppose that the incumbent commits to the access price w first, in order to influence the decision of the entrant. After observing the access price w, the entrant chooses between infrastructure-based competition (bypass) and service-based competition (access) as in the standard framework (Sappington, 2005; Gayle and Weisman, 2007; Mandy, 2009). Finally, firms simultaneously choose retail prices p_1 and p_2.

3 Strategic bypass deterrence

We solve the game by backward induction and first analyze the equilibrium of the game where the two firms choose their retail prices.

[5]In the linear model analyzed in Section 4, this condition will hold if the displacement ratio is smaller than one.

3.1 Price competition under access

Suppose that the entrant has chosen to buy access at price w. Given Assumption 1, at the price competition stage, firms' optimal behavior is characterized by the first order conditions:

$$x_1(p_1,p_2)+\frac{\partial x_1}{\partial p_1}(p_1-c_1)+\frac{\partial x_2}{\partial p_1}(w-c_1) = 0, \quad (5)$$

$$x_2(p_1,p_2)+\frac{\partial x_2}{\partial p_2}(p_2-w) = 0. \quad (6)$$

Let $(\hat{p}_1^a, \hat{p}_2^a)$ denote the solutions to these first order conditions and $\hat{\pi}_1^a, \hat{\pi}_2^a$ the profits of the two firms at prices $(\hat{p}_1^a, \hat{p}_2^a)$.

Proposition 1 *Suppose that Assumption 1 holds. The pricing game admits a unique equilibrium* $(\hat{p}_1^a, \hat{p}_2^a)$. *Furthermore, at equilibrium,* $\frac{\partial \hat{p}_1^a}{\partial w} > 0$, $\frac{\partial \hat{p}_2^a}{\partial w} > 0$ *and* $\frac{\partial \hat{\pi}_2^a}{\partial w} < 0$.

Proposition 1 establishes that in equilibrium, the prices charged by both firms are increasing in the access charge. This results rests on a simple intuition: as the access charge increases, the cost of the entrant increases raising its price. Simultaneously, the share of the access revenue in the profit of the incumbent increases, resulting in softer competition between the firms, and leading the incumbent to raise its price. Furthermore, under Assumption 1, we also show that the direct effect of an increase in access charges on the profit of the entrant outweighs the strategic effect due to an increase in equilibrium prices, so that the "natural" comparative statics result holds and $\hat{\pi}_2^a$ is decreasing in w.

The effect of an increase in w on the profit of the incumbent is more complex to ascertain. On the one hand, an increase in w, by increasing both prices, raises the profit that the incumbent makes on its retail product, $(p_1 - c_1)x_1$. On the other hand, an increase in w may reduce the demand for access, resulting in a decrease in the access revenue of the incumbent.[6] Overall, while we cannot sign the effect of an increase in w on $\hat{\pi}_1^a$, we can provide a sufficient condition under which the profit of the incumbent is *concave* in the access charge w.

[6] In the particular case of Hotelling competition with fully covered market studied by Sappington (2005), the two effects exactly cancel each other, so that the equilibrium profit of the entrant is independent of w. However, this is a special case and does not hold for general models of price competition.

Lemma 1 *Suppose that*

$$\frac{\partial p_2}{\partial w}\left[\frac{\partial^2 \pi_1^a}{\partial p_2 \partial w} + \frac{\partial^2 \pi_1^a}{\partial p_2^2}\frac{\partial p_2}{\partial w} + \frac{\partial^2 \pi_1^a}{\partial p_2 \partial p_1}\frac{\partial p_1}{\partial w}\right] + \frac{\partial^2 p_2}{\partial w^2}\frac{\partial \pi_1^a}{\partial p_2} + \frac{\partial x_2}{\partial p_1}\frac{\partial p_1}{\partial w} + \frac{\partial x_2}{\partial p_2}\frac{\partial p_2}{\partial w} < 0.$$

Then the profit of the incumbent, $\hat{\pi}_1^a$ is a concave function of w. Furthermore,

$$w^* = \operatorname*{argmax}_w \hat{\pi}_1^a > c_1.$$

Lemma 1 provides a sufficient condition for the concavity of the incumbent's profit in the access charge, and shows that the optimal access charge is always higher than the marginal cost c_1. Notice that we do not rule out the fact that the profit of the incumbent is continuously increasing in the access charge, so that the optimal level is the corner solution $w^* = \overline{p}$. Unfortunately, the sufficient condition of Lemma 1 cannot be written easily in terms of the primitive demand functions x_1 and x_2. The condition will be satisfied when the price of the entrant is a concave function of w. However, the relation between p_2 and w cannot be too concave, as $(\frac{\partial p_2}{\partial w} + w\frac{\partial^2 p_2}{\partial w^2} > 0)$. The condition also requires that the own effect of a change in prices on the demand of the incumbent $\frac{\partial x_2}{\partial p_2}$ be sufficiently higher than the cross effect $\frac{\partial x_2}{\partial p_1}$ so that $(1 - \frac{\partial p_2}{\partial w})\frac{\partial x_2}{\partial p_2} + (1 - \frac{\partial p_1}{\partial w})\frac{\partial x_2}{\partial p_1} < 0$. In Section 4, we compute the exact restrictions on parameters needed to guarantee that the condition holds when demand functions are linear.

3.2 Price competition under bypass

Suppose that the entrant has chosen to build its own infrastructure. The equilibrium prices are now characterized by the first order conditions:

$$x_1(p_1, p_2) + \frac{\partial x_1}{\partial p_1}(p_1 - c_1) = 0, \tag{7}$$

$$x_2(p_1, p_2) + \frac{\partial x_2}{\partial p_2}(p_2 - c_2) = 0. \tag{8}$$

Denoting the solution to the first order conditions by $(\hat{p}_1^b, \hat{p}_2^b)$ with corresponding profits $\hat{\pi}_1^b$ and $\hat{\pi}_2^b$, we show:

Proposition 2 *Suppose that Assumption 1 holds. The pricing game admits a unique equilibrium $(\hat{p}_1^b, \hat{p}_2^b)$. Furthermore, at equilibrium, $\frac{\partial \hat{p}_1^b}{\partial c_1} > 0$, $\frac{\partial \hat{p}_2^b}{\partial c_2} > 0$ and $\frac{\partial \hat{\pi}_2^b}{\partial c_2} < 0$.*

Proposition 2 shows that, under Assumption 1, we obtain the well-known comparative statics effects of marginal costs on equilibrium prices and profits: an increase in the marginal cost of firm i results in an increase in equilibrium prices and a decrease in the equilibrium profit of firm i.

3.3 Access vs. bypass

We now analyze the entrant's choice between bypass and access. The entrant's 'make-or-buy' decision depends on the comparison between the profits $\hat{\pi}_2^a(w)$ and $\hat{\pi}_2^b$. As $\hat{\pi}_2^a(w)$ is strictly decreasing in the access charge, we can compute the threshold value of the access price $\tilde{w}$ which makes the entrant indifferent between access and bypass:

$$\hat{\pi}_2^a(\tilde{w}) = \hat{\pi}_2^b(c_2). \tag{9}$$

By a slight abuse of notations, denote $\hat{\pi}_2^a(x)$ and $\hat{\pi}_2^b(x)$ the equilibrium profit of the entrant as a function of the input cost of the entrant (respectively w and c_2) in the access and bypass regimes, and $\hat{\pi}_1^a(x)$ and $\hat{\pi}_1^b(x)$ the equilibrium profit of the incumbent as a function of the input cost of the entrant in the access and bypass regimes. By Assumption 1, the direct effect of an increase in cost outweighs the strategic effect, so that $\hat{\pi}_2^a(x)$ and $\hat{\pi}_2^b(x)$ are both *decreasing* functions. Hence, equation (9) characterizes a unique access charge $\tilde{w}$ which makes the entrant indifferent between making or buying (as long as $\hat{\pi}_2^a(0) > \hat{\pi}_2^b(c_2)$) and by the Implicit Function Theorem, the threshold access charge $\tilde{w}$ is *increasing* in the marginal cost c_2. In addition, we obtain the following comparison of profits in the access and bypass régimes.

Lemma 2 *For any $x < w^*$. If $x < c_1$, $\hat{\pi}_2^b(x) > \hat{\pi}_2^a(x)$ and $\hat{\pi}_1^b(x) > \hat{\pi}_1^a(x)$. If $x > c_1$, $\hat{\pi}_2^b(x) < \hat{\pi}_2^a(x)$ and $\hat{\pi}_1^b(x) < \hat{\pi}_1^a(x)$. If $x = c_1$, $\hat{\pi}_2^b(x) = \hat{\pi}_2^a(x)$ and $\hat{\pi}_1^b(x) = \hat{\pi}_1^a(x)$.*

Lemma 2 is a fundamental result, which drives the analysis of the model of strategic bypass deterrence. It shows that the incumbent and entrant rank the two régimes of access and bypass in the same way. They both prefer bypass to access when the input cost of the entrant is greater than c_1, and they both prefer access to bypass when the input cost of the entrant is lower than c_1. In order to grasp intuition about Lemma 2, recall that the difference between access and bypass régimes is that in access, the incumbent provides two goods: the final retail good at price p_1 and access to the network at price w. If $w < c_1$, the incumbent loses money on access (the opportunity cost of access is negative), and has an incentive to price aggressively in order to reduce demand for good 2. Hence, under access, the entrant faces high access charges and low demand, whereas the incumbent makes losses on access and prices aggressively; both the entrant and incumbent prefer bypass to access. On the other hand, when $w^* > w > c_1$, the incumbent makes profit on access, and increases prices to soften competition. Hence, under access, the entrant faces higher prices and lower charges, whereas the incumbent makes profit on access and chooses high prices; both the entrant and incumbent prefer access to bypass.

Given Lemma 2 and equation (9), if $c_2 < c_1$, $\tilde{w}(c_2) < c_2$, and if $c_2 > c_1$, $\tilde{w}(c_2) > c_2$. If the cost of the entrant is lower than the cost of the incumbent, the incumbent needs to reduce her access charge below c_2 in order to induce access. By contrast, if the cost of the entrant is higher than the cost of the incumbent, the incumbent can induce access with an access charge above c_2. Figure 1 illustrates this observation, by displaying the profit of the entrant under bypass and access as a function of the entrant's cost x. It shows the limit access charge $\tilde{w}$ for two values of the entrant's cost, $c_2 < c_1$ and $c_2' > c_1$.

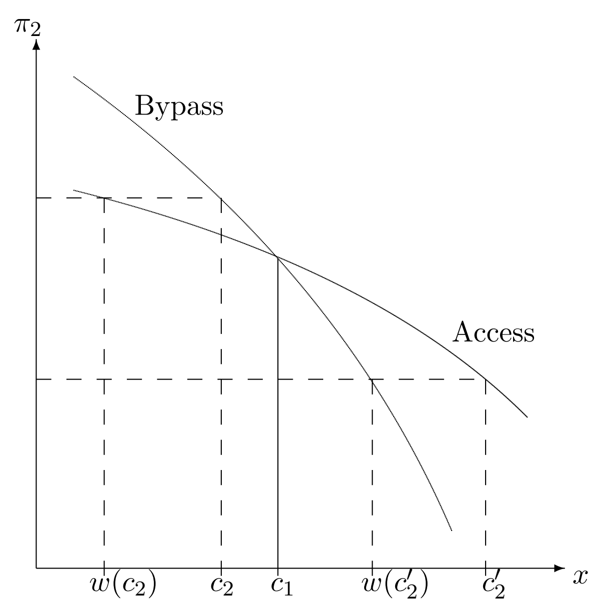

Figure 1: Entrant's profit under bypass and access

Turning to the incumbent's profit, Figure 2 shows the profit under bypass and access for different values of the entrant's input cost, x. Notice that, by Lemma 1, the optimal access charge w^* satisfies $w^* \geq c_1$. Hence, the optimal régimes for the incumbent are (i) to choose bypass whenever $x < c_1$, and access whenever $x > c_1$.

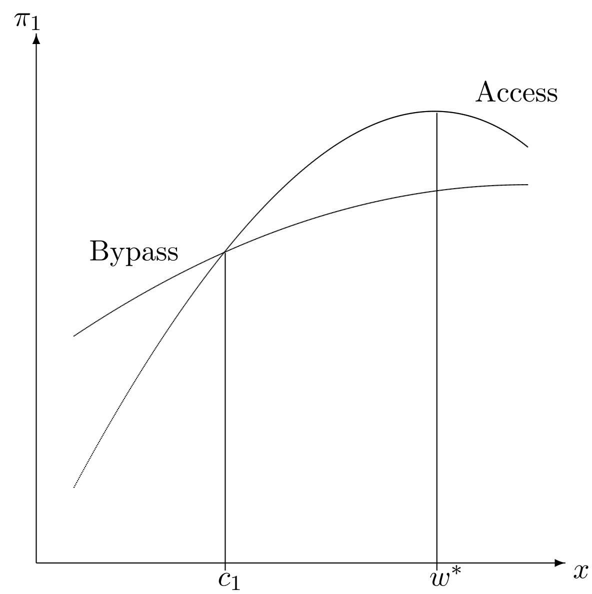

Figure 2: Incumbent's profit under bypass and access

3.4 Optimal choice of the access charge

We now consider the optimal choice of the access charge by the incumbent. First note that the incumbent will never choose an access charge $w > w^*$ if the entrant chooses access. We thus restrict attention to access charges in $[0, w^*]$.

We first consider a situation where the entrant is more efficient than the incumbent, $c_2 < c_1$. By the observation underlying Figure 1, whenever $c_2 < c_1$, the limit access charge satisfies $\tilde{w}(c_2) < c_2$. Hence, in order to deter bypass, the incumbent has to choose a low access price $\tilde{w}(c_2) < c_2$. As $c_2 < c_1$, $\pi_1^b(c_2) > \pi_1^a(c_2) > \pi_1^a(\tilde{w}(c_2))$, so the incumbent prefers to allow bypass at cost c_2 than to promote access.

Next, consider the case where the incumbent is more efficient than the entrant, $c_2 > c_1$, so that the limit access charge satisfies $\tilde{w}(c_2) > c_2$. We distinguish between two cases. First, suppose that $\tilde{w}(c_2) < w^*$. As $c_2 > c_1$, $\pi_1^a(\tilde{w}(c_2)) > \pi_1^a(c_2) > \pi_1^b(c_2)$. Hence, the incumbent optimally chooses to charge the limit access price $\tilde{w}(c_2)$ in order to deter bypass. Second, suppose that $\tilde{w}(c_2) \geq w^*$. Then, by setting the optimal access charge w^*, the incumbent deters bypass. As $\pi_1^a(w^*) > \pi_1^a(c_2) > \pi_1^b(c_2)$, the optimal strategy of the incumbent is to select the optimal access charge w^* and to deter bypass. We summarize the discussion in the following Proposition.

Proposition 3 *The incumbent sets the access charge w as follows. if $c_2 < c_1$, bypass occurs. If $c_1 \leq c_2 < \tilde{w}^{-1}(w^*)$, the incumbent sets the limit access charge $\tilde{w}(c_2)$ to deter bypass. If $c_2 \geq \tilde{w}^{-1}(w^*)$, the incumbent sets the optimal access charge w^* and deters bypass.*

Proposition 3 characterizes the limit pricing behavior of the incumbent in a model of access and bypass. By analogy with a model of strategic entry deterrence, we characterize three régimes. When the cost of the entrant is low ($c_2 < c_1$), the incumbent prefers to *accommodate bypass*. When the cost of the entrant is intermediate ($c_1 \leq c_2 < \tilde{w}^{-1}(w^*)$), the incumbent chooses to *prevent bypass* by setting a limit access charge $\tilde{w}(c_2)$. Finally, when the cost of the entrant is large ($c_2 \geq \tilde{w}^{-1}(w^*)$), *bypass is blocked* at the optimal access charge w^* so that the incumbent does not need to distort his pricing strategy to deter bypass. We remark that the optimal behavior of the incumbent always induces a *technologically efficient* choice: the entrant chooses bypass whenever $c_2 < c_1$ and access whenever $c_2 > c_1$.[7]

3.5 Welfare and regulation

In order to assess the welfare implications of the equilibrium of the game played by the incumbent and the entrant, we suppose that demand functions are generated by a competitive market with a mass one of consumers with a representative quasi-linear utility function

$$U = U(x_1, x_2) - p_1 x_1 - p_2 x_2.$$

To conduct the analysis, we make the following Assumptions on the utility function:

[7] This is also reflected in the analysis of Mandy (2009) who did not endogenize the choice of access charges. The endogenous access charge in our model lies in the set of efficient access prices identified by Mandy (2009).

Assumption 2 *We suppose that $U(x_1, x_2)$ is increasing and concave, that both goods are normal goods and that the following conditions are satisfied:*

$$\begin{aligned} x_1 &\geq -\frac{\frac{\partial^2 U}{\partial x_1 \partial x_2}\frac{\partial U}{\partial x_2}}{\frac{\partial^2 U}{\partial x_1^2}\frac{\partial^2 U}{\partial x_2^2} - \frac{\partial^2 U}{\partial x_1 \partial x_2}}, \\ x_2 &\geq -\frac{\frac{\partial^2 U}{\partial x_1 \partial x_2}\frac{\partial U}{\partial x_1}}{\frac{\partial^2 U}{\partial x_1^2}\frac{\partial^2 U}{\partial x_2^2} - \frac{\partial^2 U}{\partial x_1 \partial x_2}}. \end{aligned}$$

Because the utility function is quasi-linear in income, the Marshallian consumer surplus is a well-defined welfare measure. Assumption 2 guarantees that any increase in prices will harm consumers, and will be needed to compare consumer welfare under access and bypass régimes. Total welfare is defined by:

$$\begin{aligned} W &= (1-\lambda)U + \lambda(\pi_1 + \pi_2), \\ &= (1-\lambda)(U(x_1, x_2) - p_1 x_1 - p_2 x_2) \\ &+ \lambda((p_1 - c_1)x_1(p_1, p_2) + (p_2 - \theta)x_2(p_1, p_2)), \end{aligned}$$

where λ is the share of firms in total welfare, $\theta = c_1$ in the case of access and $\theta = c_2$ in the case of bypass. Let $U^a(x)$ and $U^b(x)$ denote the consumer's utility under access and bypass when the access charge is x. As prices are increasing in the access charge by Proposition 2, and consumer surplus is decreasing in prices, there exists a unique value of the entrant's cost, $\bar{c}_2$, such that

$$U^a(w^*) = U^b(\bar{c}_2).$$

Comparing welfare under access and bypass, we find that consumers and firms have opposite preferences over the two régimes when $c_2 < \bar{c}_2$:

Proposition 4 *If $c_2 < c_1$, $U^a(\tilde{w}(c_2)) > U^b(c_2)$ and if $\bar{c}_2 > c_2 > c_1$, $U^b(c_2) > U^a(\min w^*, \tilde{w}(c_2))$ and if $c_2 > \bar{c}_2$, $U^a(w^*) > U^b(c_2)$. Furthermore, $\bar{c}_2 > w^*$.*

The intuition underlying Proposition 4 is easy to grasp: while firms benefit from higher prices, consumers are harmed by régimes under which prices are higher and competition softer. When the entrant is more efficient than the incumbent, consumers would prefer the incumbent to impose access at a price $\tilde{w}(c_2) < c_1$ at which she makes losses on access, resulting in low prices and strong competition. When the incumbent is more efficient than the entrant and $c_2 < \bar{c}_2$, the consumers prefer to encourage bypass, because competition between the two firms is fiercer and prices are lower. When $c_2 > \bar{c}_2$, bypass becomes too expensive, and prices are lower at access when the incumbent charges his optimal access charge w^*.

Proposition 4 thus shows the existence of a fundamental tension between consumer surplus and firms' profits, which make it impossible to clearly assess the régime which maximizes total welfare W when $c_2 < \bar{c}_2$. In addition, we note that there exists a tension between *production efficiency* which specifies that access should be chosen when $c_1 < c_2$ and bypass should be chosen when $c_2 < c_1$ and *economic efficiency* which specifies that prices should be as low as possible to maximize total surplus. In particular, note that when $c_1 < c_2 < \bar{c}_2$, access is technologically efficient, but results in higher retail prices than bypass. This is due to the fact that the limit access charge $\tilde{w}(c_2)$ is always higher than the marginal cost c_2 of the entrant when $c_2 > c_1$. We thus obtain the seemingly paradoxical result that in equilibrium firms choose the régime with the lowest production costs and the highest retail prices.

3.5.1 Access regulation

We first consider a situation where the regulator cannot choose the access price, but can impose the access or bypass régime. Suppose that the welfare function of the regulator coincides with consumer surplus. If $c_2 < c_1$, the regulator would like to prevent bypass and impose access, forcing the incumbent into losses.[8] If $c_2 > \bar{c}_2$, the incentives of consumers and firms are aligned, and access is optimal. If $\bar{c}_2 > c_2 > c_1$, the regulator would like to encourage bypass whereas the incumbent and the entrant would prefer access. This is a situation where the regulator should optimally limit the use of the existing infrastructure by the entrant, and force the entrant to build his own network. Notice that, in dynamic models, third-party access to infrastructure has been criticized on the grounds that it delays investment in alternative and better infrastructure. In our analysis, we see that mandatory access to infrastructure leads to higher retail prices and that productive efficiency is achieved at the expense of the consumers. Restricting the possibility of access may thus be valuable both from a static and dynamic point of view.

[8] If the regulator cannot impose losses to the incumbent, this regulatory tool will not be available.

3.5.2 Access price regulation

The alternative to restricting the possibilities of access is to regulate the access price and the access conditions under mandatory access. When the threat of bypass is absent, access price regulation is essential to avoid monopolization or market foreclosure.[9] When alternative infrastructure are economically viable, access price regulation might be softer or eventually removed. Indeed, the cost of implementing a fully-fledged regulation at the wholesale level may exceed the benefit. Along this line, Peitz (2005) argues that in a mature market, regulatory interventions should be replaced by ex-post control by antitrust authorities. Indeed, in many countries, there is no longer an ex-ante price regulation for wholesale services in the telecommunication markets.

Suppose that the regulator is constrained and can only intervene ex-post to modify locally the access price set by the incumbent. We observe that, in the limit pricing régime, any *local variation* in the access price would benefit the consumers. A slight decrease in the access price would not change the entrant's make-or-buy decision but it would lead to lower retail prices. A slight increase in the access price would lead to a switch from access to bypass by the entrant and also result in a decrease in the retail prices. In the constrained access regime, a regulator has always incentives to intervene ex-post to modify the wholesale market price.

4 A linear example

In this section, we illustrate the analysis of the strategic deterrence game by looking at a linear model where demands are given by

$$x_i(p_i, p_j) = 1 - p_i + \delta p_j,\ \ i, j = 1, 2,\ i \neq j,\ \ \delta < 1. \tag{10}$$

The parameter $\delta \in (0, 1)$ is the *displacement ratio* which indicates how an increase in the price of good j raises the demand of good i. We now check that Assumption 1 is satisfied. The first part of the Assumption requires $\delta < 2$. The second part of the Assumption holds if and only if the displacement ratio δ is smaller than one.

4.1 Equilibrium analysis

We first compute the price equilibrium in the access case, and find:

[9] See Laffont and Tirole (1994).

$$\hat{p}_1^a = \frac{2 + 2c_1(1-\delta) + \delta + 3\delta w}{4-\delta^2},$$
$$\hat{p}_2^a = \frac{2 + c_1\delta(1-\delta) + \delta + (2+\delta^2)w}{4-\delta^2}.$$

The demands are given by:

$$\hat{x}_1^a = \frac{2 + \delta - \delta w(1-\delta^2) - c_1(1-\delta)(2-\delta^2)}{4-\delta^2},$$
$$\hat{x}_2^a = \frac{2 + \delta + c_1\delta(1-\delta) - 2w(1-\delta^2)}{4-\delta^2},$$

and the equilibrium profits:

$$\begin{aligned}
\hat{\pi}_1^a &= \frac{[2 - c_1(2+2\delta-\delta^2) + \delta + 3w\delta][2 + \delta - \delta w(1-\delta^2) - c_1(1-\delta)(2-\delta^2)]}{(4-\delta^2)^2} \\
&+ \frac{[(w-c_1)(4-\delta^2]][2 + \delta + c_1\delta(1-\delta) - 2w(1-\delta^2)]}{(4-\delta^2)^2}, \\
\hat{\pi}_2^a &= \frac{(2 + \delta + c_1\delta(1-\delta) - 2w(1-\delta^2))^2]}{(4-\delta^2)^2}.
\end{aligned}$$

We easily check that the two prices p_1^a and p_2^a are increasing in w, that the profit of the incumbent is concave in w, and the profit of the entrant decreasing in w. We compute the optimal access charge of the incumbent as:

$$w^* = \frac{8 + \delta^3 + c_1(1-\delta)(8 + 2\delta^2 - \delta^3)}{2(1-\delta)(8+\delta^2)}.$$

Observe that the optimal access charge is linearly increasing in the unit cost of the incumbent c_1, and is increasing in the displacement parameter δ. For $\delta = 0$, when the two markets are independent, the incumbent chooses the access charge which is equal to the wholesale price chosen by an integrated monopolist, $w^* = \frac{1+c}{2}$. As δ increases, the incumbent has a higher incentive to raise the access charge, as it also softens competition and increases profits on the retail market. Figure 3 illustrates this monotonic relation, by plotting the optimal access charge as a function of δ when $c_1 = 0.2$.

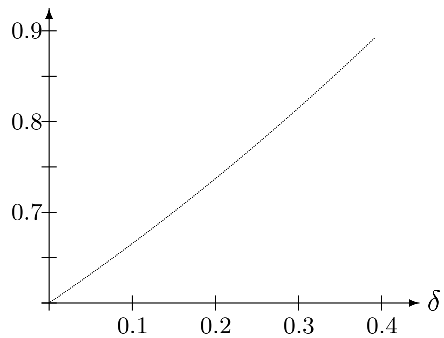

Figure 3: Optimal access charge

We now turn to the pricing equilibrium of the bypass model. We solve the equilibrium prices as:

$$\hat{p}_1^b = \frac{2+\delta+2c_1+c_2\delta}{4-\delta^2},$$
$$\hat{p}_2^b = \frac{2+\delta+2c_2+c_1\delta}{4-\delta^2}.$$

with equilibrium quantities:

$$\hat{x}_1^b = \frac{2+\delta-c_1(2-\delta^2)+\delta c_2}{4-\delta^2},$$
$$\hat{x}_2^b = \frac{2+\delta-c_2(2-\delta^2)+\delta c_1}{4-\delta^2}$$

and equilibrium profits:

$$\hat{\pi}_1^b = \frac{(2+\delta-(2-\delta^2)c_1+\delta c_2)^2}{(4-\delta^2)^2},$$
$$\hat{\pi}_2^b = \frac{(2+\delta-(2-\delta^2)c_2+\delta c_1)^2}{(4-\delta^2)^2}$$

The limit access charge $\tilde{w}(c_2)$ can now be computed as:

$$\tilde{w} = \frac{c_2(2-\delta^2) - c_1\delta^2}{2(1-\delta^2)}.$$

We note that the limit access charge is a linearly increasing function of c_2 and a linearly decreasing function of c_1. In accordance with Lemma 2, we observe that $\tilde{w} > c_2$ if and only if $c_1 > c_2$. Figure 4 shows how the limit access price $\tilde{w}$ varies with the displacement ratio δ both when $c_2 = 0.2 > c_1 = 0.1$ (the upper curve) and when $c_1 = 0.2 > c_2 = 0.1$ (the lower curve). When the incumbent is more efficient than the entrant, the limit access price increases with δ, so that one should observe higher access charges when firms are closer substitutes. If, on the other hand, the entrant is more efficient than the incumbent, the limit access price decreases with δ, but this case never arises at equilibrium, as the incumbent always chooses to accommodate bypass.

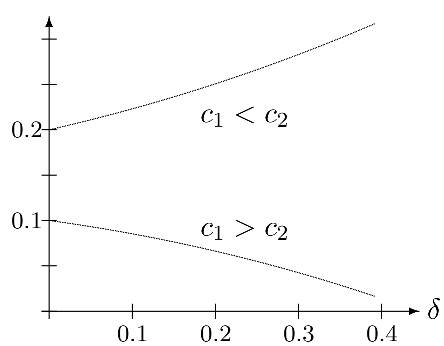

Figure 4: Limit access charge

4.2 Welfare Analysis

It is well-known that linear demand functions in a differentiated duopoly can be generated by the quasi-linear utility function

$$U(x_1, x_2) = \sum_{i=1,2} \left[\alpha x_i - \beta \frac{x_i^2}{2}\right] - \gamma x_1 x_2 - \sum_{i=1,2} p_i x_i, \tag{11}$$

with $\alpha = \frac{1}{1-\delta}$, $\beta = \frac{1}{1-\delta^2}$ and $\gamma = \frac{\delta}{1-\delta^2}$. We recall that the welfare function is a weighted sum of consumers' utilities and firm's profits,

$$\begin{aligned} W &= (1-\lambda)(\alpha(x_1+x_2) - \beta(x_1^2+x_2^2) - \gamma x_1 x_2 - p_1 x_1 - p_2 x_2), \\ &+ \lambda(p_1 x_1 + p_2 x_2 - c_1 x_1 - \theta x_2), \end{aligned}$$

with $\theta = c_1$ in the case of access and $\theta = c_2$ in the case of bypass. Fixing $\delta = 0.4, c_1 = 0.2$; we now compute the welfare function W both at the access régime when $w = \tilde{w}(c_2)$ and at the bypass régime for different values of c_2 and λ. The results are reported in Table 1.

	$c_2 = 0.1$		$c_2 = 0.3$		$c_2 = 0.99$	
λ	W^a	W^b	W^a	W^b	W^a	W^b
0	0.1594	0.1536	0.1293	0.1339	0.0539	0.0516
0.5	0.3699	0.4011	0.3760	0.3507	0.3274	0.2404
1	0.5805	0.6436	0.6227	0.5661	0.6003	0.4292

Table 1: Welfare under access and bypass

Table 1 shows that, for low values of the entrant cost, $c_2 = 0.1$, the preferences of consumers and of the firms are opposite: consumers prefer access whereas firms prefer bypass. When they are given equal weight in the welfare function, bypass is chosen. For intermediate values of the entrant cost, $c_2 = 0.3$, consumers favor bypass whereas firms prefer access. With equal weights to consumers and firms in the welfare function, access is preferred. Finally, for very high values of the entrant cost ($c_2 = 0.99$), the preferences of consumers and firms are aligned, and they both prefer access.

5 Extensions

5.1 Fixed cost

In the analysis so far, we have assumed that the entrant faces no fixed entry cost. This assumption is unlikely to hold in some industries, like the telecommunications industry, where firms can only enter after they invest in a network. In the first extension, we suppose that the entrant incurs a fixed cost f_2 to enter the market. In classical models of industrial organization, fixed costs have no influence on pricing decisions but only affect the participation decision. In our framework, this is no longer the case, as the fixed cost affects the limit access charge and hence the retail prices when the incumbent chooses to deter access. Hence, higher fixed costs will ultimately result in higher consumer prices in our model.

At the price setting stage, once fixed costs have been paid, the equilibrium retail prices are identical to those computed for the baseline model, and are characterized in Propositions 1 and 2. However, at the earlier stage of the game, the make-or-buy decision is affected by the fixed cost, as the entrant will choose to enter as long as $w \leq \tilde{w}(c_2, f_2)$, which is implicitly defined by:

$$\hat{\pi}_2^a(\tilde{w}(c_2, f_2)) = \hat{\pi}_2^b(c_2) - f_2. \tag{12}$$

Clearly, the presence of the fixed cost makes bypass less attractive, allowing the incumbent to charge a higher access price to deter bypass. Hence, the limit access charge $\tilde{w}(c_2, f_2)$ is increasing in f_2. Furthermore, as $\frac{\partial p_1^a}{\partial w} > 0$ and $\frac{\partial p_2^a}{\partial w} > 0$, higher fixed costs result in higher prices and lower consumer utility in the parameter region where the incumbent chooses to deter bypass.[10] As consequences, given that retail prices increase with the wholesale price, consumers face higher prices when the incumbent deters bypass.

Regarding the optimal access charge, we can replicate the above arguments to show that when the entrant has a higher marginal cost than the incumbent, the incumbent either sets the minimum of the optimal access charge w^* and the limit access charge $\tilde{w}(c_2, f_2)$. But, contrary to the previous case, when the entrant has a lower marginal cost than the incumbent, bypass does not necessarily occur. Indeed, as the access price $\tilde{w}$ is higher when $f_2 > 0$, it is no longer true that $\tilde{w}(c_2, f_2) < c_2$ when $c_2 < c_1$. Nevertheless, we can identify a fixed cost threshold such that bypass occurs when the fixed cost is below the threshold.

Proposition 5 *The incumbent sets the access charge w as follows. if $c_1 < c_2$, $w = \min[\tilde{w}(c_2, f_2), w^*]$ and the entrant chooses access. If $c_2 < c_1$, define the two threshold fixed cost levels $\bar{f}_2$ and $\bar{\bar{f}}_2$ by:*

$$\begin{aligned} \tilde{w}(c_2, \bar{f}_2) &= w^*, \\ \pi_1^a(\tilde{w}(c_2, \bar{\bar{f}}_2)) &= \pi_1^b(c_2). \end{aligned}$$

If $f_2 < \min\{\bar{f}_2, \bar{\bar{f}}_2\}$, the incumbent selects bypass. If $f_2 \geq \min\{\bar{f}_2, \bar{\bar{f}}_2\}$, the incumbent deters bypass either at an access charge w^* (if $f_2 > \bar{f}_2$) or at the limit access charge $\tilde{w}(c_2, f_2)$ (if $\bar{f}_2 > f_2 > \bar{\bar{f}}_2$).

[10] Notice that any fixed cost f_1 incurred by the incumbent has no influence on pricing decisions, as it is sunk before the access or bypass decision is made.

It is instructive to compare Proposition 5 with Proposition 3. When the incumbent is more efficient, access is chosen with or without fixed costs, and the incumbent's decision leads to an efficient technological choice. If the entrant has a lower unit cost, the definition of technological efficiency is more complex, as it depends on the total quantities supplied of the two goods. In addition, the incumbent's decision depends on the fixed cost level. If the fixed cost level is sufficiently high, the incumbent can impose access at a high level of the access charge (either w^* or $\tilde{w}(c_2, f_2)$ and will optimally choose to impose access. If the fixed cost level is low, as in Proposition 3, the incumbent will prefer to allow bypass. A fixed infrastructure cost for the entrant thus results in a larger parameter space for which access occurs. As access is associated with softer competition and higher retail prices, this induces a decrease in consumers' utility. For this reason, when alternative infrastructures are viable, mandatory access should be considered with caution.

5.2 Alternative timing

In the baseline model, we assume that the incumbent can commit to the access charge w before the entrant chooses whether to bypass the network, and before prices are chosen. As in classical models of entry deterrence, this assumption relies on the incumbent's technological possibility to commit to the access charge w. In this section, we briefly analyze the game under alternative sequences of decisions.

5.2.1 Simultaneous moves

Consider first the simultaneous moves game where the incumbent cannot commit to the access price w and selects instead p_1 and w at the same time as the entrant selects p_2. A rapid inspection of the incumbent's profit under access, (equation (1)), shows that for fixed p_1 and p_2, the incumbent's profit is increasing in w. Hence, in an access régime, the incumbent has an incentive to select a price $w = p_2$ which captures all the rents that the entrant makes on the retail market. Knowing this, the entrant never chooses to buy access and prefers instead to build its own network. We thus obtain:

Proposition 6 *In the simultaneous move game, in equilibrium, the entrant always bypasses.*

Proposition 6 is reminiscent of similar results in the entry deterrence literature: if the incumbent cannot commit to the limit price, it cannot deter entry and must accommodate the entrant. This result shows how important the commitment technology is for the incumbent, and suggests that the incumbent may prefer to entrust the choice to a third party (like a regulation agency) in order to guarantee commitment.

5.2.2 Stackelberg leadership

In this extension, we modify the order of moves by assuming that the incumbent behaves as a Stackelberg leader and selects the retail price p_1 and the access charge w before the entrant chooses access or bypass and its retail price p_2.[11]

At the last stage of the game, given p_1 and w, the entrant's profit under access and bypass are given by:

$$\begin{aligned} \pi_2^a &= (p_2 - w)x_2(p_1, p_2) \qquad (13) \\ \pi_2^b &= (p_2 - c_2)x_2(p_1, p_2) \qquad (14) \end{aligned}$$

Let us define by $p_2^{a*}(p_1, w)$ and $p_2^{b*}(p_1)$, the profit maximizing price under access and bypass respectively. Given that the incumbent sets its price before the make-or-buy choice of the entrant, the most profitable option is the cheapest one. Thus, the entrant bypasses if $w < c_2$ and uses the incumbent's network otherwise. The bypass deterrent price $\tilde{w}$ is thus equal to the entrant's marginal cost c_2.

Anticipating the entrant's behavior, the incumbent's profit is given by

$$\begin{aligned} \pi_1^a &= (p_1 - c_1)x_1(p_1, p_2^{a*}) + (w - c_1)x_2(p_1, p_2^{a*}) \text{ if } w \leq c_2 \\ \pi_1^b &= (p_1 - c_1)x_1(p_1, p_2^{b*}) \text{ if } w > c_2 \end{aligned}$$

The incumbent chooses the price pair (p_1, w) that maximizes its profit. We can identify three candidate equilibria:

1. (p_1^{a**}, w^{**}) defined as the unconstrained maximizers of π_1^a,
2. (p_1^{a*}, c_2) where p_1^{a*} is defined as the maximizer of π_1^a when $w = c_2$,
3. $(p_1^{b*}, w > c_2)$ where p_1^{b*} is defined as the maximizer of π_1^b.

Comparing the three candidate equilibrium, the optimal access charge is given by:

[11] Bloch and Gautier (2008) consider a similar timing for the case of regulated retail and wholesale prices for the incumbent.

Proposition 7 *The incumbent sets the access charge w as follows: If $c_2 < c_1$, bypass occurs. If $c_1 \leq c_2 < w^{**}$, the incumbent sets the limit access charge $\tilde{w} = c_2$ to deter bypass. If $c_2 \geq w^{**}$, the incumbent sets the optimal access charge w^{**} and deters bypass.*

With this alternative timing, the incumbent commits to its wholesale and retail price. Thus, for any given retail price p_1 that will be applied in both régimes, the entrant chooses the cheapest option for production: bypass if $c_2 < w$ and access otherwise. The bypass deterrent price is thus equal to the entrant's marginal cost c_2. This price applies as long as the incumbent is more cost effective than the entrant and the bypass deterrent price is lower than w^{**}.

6 Concluding remarks

In liberalized network industries, entrants can either compete for service using the existing infrastructure (access) or deploy their own infrastructure capacity (bypass). In this paper, we analyze a game played by an incumbent and an entrant, where the incumbent selects the access charge optimally, taking into account the subsequent decision of the entrant. By analogy with strategic entry deterrence, we show that there exist three régimes: one where the incumbent accommodates bypass, one where the incumbent blocks bypass by choosing the optimal access charge, and one where the incumbent selects a limit access price to deter bypass. Interestingly, the optimal choice of the unregulated incumbent leads to a technologically efficient situation, where the most efficient firm produces the network good. However, production efficiency is realized at the expense of allocative efficiency, and retail prices are too high. By preventing access and encouraging bypass, the regulator could increase social welfare. In two extensions of the model, we show that the characterization of the three régimes is robust to the introduction of a fixed cost of entry, that commitment is essential to deter bypass, and that the incumbent would benefit from a first mover advantage.

Our analysis provides an exhaustive picture of the behavior of an unregulated incumbent in a network industry, showing the tension between allocative and productive efficiency when alternative infrastructures are viable but not necessarily more efficient. In this case, competition (or potential competition) between technologies at the wholesale stage does not suppress the need for regulation. We did not consider a 'first best' regulation that would control both the access price and the make-or-buy choice made by the entrant because such a regulation is informationally demanding as it requires to know the costs of both the entrant and the incumbent. We rather consider 'second-best' regulation where the regulator either controls the make-or-buy choice by making access provision mandatory or not or has the ability to intervene ex-post to modify locally the access price. These two limited instruments prove to be useful to reduce retail prices and sometimes to increase the welfare.

Regulation of access is still at the heart of a quite vivid debate in the telecommunication industry where access regulation should promote retail competition and investments in next generation network. Our results particularly emphases on the consequences on retail prices of promoting access to existing infrastructure but we left aside the question of optimal regulatory policy.

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7 Appendix

Proof of Proposition 1: For any p_2, let $\phi_1(p_2)$ denote the unique solution to equation (5) and for any p_1, let $\phi_2(p_1)$ denote the unique solution to equation (6). We construct the function $\phi : [0, \overline{p}]^2 \to [0, \overline{p}]^2$ as $\phi(p_1, p_2) = (\phi_1(p_2), \phi_2(p_1))$. The function ϕ is increasing and hence, it admits a fixed point by Tarski's theorem. It is easy to check that any fixed point of the function ϕ is a Nash equilibrium of the pricing game.

In addition, we check that $1 > \phi_1'(p_2) > 0$ and $1 > \phi_2'(p_1) > 0$, guaranteeing that the fixed point is unique. In order to compute $\frac{\partial \hat{p}_1^a}{\partial w}$ and $\frac{\partial \hat{p}_2^a}{\partial w}$, we differentiate the first order conditions (5) and (6) with respect to w to obtain:

$$\begin{aligned}
\frac{\partial^2 \pi_1^a}{\partial p_1^2}\frac{\partial p_1}{\partial w} + \frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{\partial p_2}{\partial w} &= -\frac{\partial x_2}{\partial p_1}, \\
\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2}\frac{\partial p_1}{\partial w} + \frac{\partial^2 \pi_1^a}{\partial p_2^2}\frac{\partial p_2}{\partial w} &= \frac{\partial x_2}{\partial p_2}.
\end{aligned}$$

Solving the system of linear equations,

$$\begin{aligned}
\frac{\partial p_1}{\partial w} &= \frac{-\frac{\partial x_2}{\partial p_1}\frac{\partial^2 \pi_1^a}{\partial p_1^2} - \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}}{D}, \\
\frac{\partial p_2}{\partial w} &= \frac{\frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1^2} + \frac{\partial x_2}{\partial p_1}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}}{D},
\end{aligned}$$

where

$$D = \frac{\partial^2 \pi_1^a}{\partial p_1^2}\frac{\partial^2 \pi_2^a}{\partial p_2^2} - \frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2} > 0.$$

We immediately check that $\frac{\partial p_1}{\partial w} > 0$ and $\frac{\partial p_2}{\partial w} > 0$. Now, observe that

$$\frac{\partial \pi_2^a}{\partial w} = \frac{\partial \pi_2^a}{\partial p_1}\frac{\partial p_1}{\partial w} - x_2.$$

Replacing x_2 using the first order condition (6), and noting that $\frac{\partial \pi_2^a}{\partial p_1} = (p_2 - w)\frac{\partial x_2}{\partial p_1}$,

$$\frac{\partial \pi_2^a}{\partial w} = (p_2 - w)(\frac{\partial x_2}{\partial p_1}\frac{\partial p_1}{\partial w} + \frac{\partial x_2}{\partial p_2}).$$

The first term in this expression is the *strategic effect* which is always positive: An increase in w increases p_1, enabling the entrant to charge a higher price p_2. The second term is the *direct effect* which is always negative: An increase in w reduces the entrant's profit margin. We show that under assumption 1, the direct effect dominates the strategic effect. We write:

$$\text{sign}\ \frac{\partial \pi_2^a}{\partial w} = \text{sign}\ \frac{\partial x_2}{\partial p_1}\frac{-\frac{\partial x_2}{\partial p_1}\frac{\partial^2 \pi_1^a}{\partial p_1^2} - \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}}{\frac{\partial^2 \pi_1^a}{\partial p_1^2}\frac{\partial^2 \pi_2^a}{\partial p_2^2} - \frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2}} + \frac{\partial x_2}{\partial p_2}.$$

Hence, to prove that $\frac{\partial \pi_2^a}{\partial w} < 0$, it suffices to show that:

$$\begin{aligned} & -(\frac{\partial x_2}{\partial p_1})^2\frac{\partial^2 \pi_1^a}{\partial p_1^2} - \frac{\partial x_2}{\partial p_1}\frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2} \\ & + \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1^2}\frac{\partial^2 \pi_2^a}{\partial p_2^2} - \frac{\partial x_2}{\partial p_2}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{\partial^2 \pi_2^a}{\partial p_1 \partial p_2} \quad < \quad 0. \end{aligned}$$

which is the second condition in Assumption 1.

Proof of Lemma 1: By the envelope theorem, we compute

$$\frac{d\pi_1^a}{dw} = \frac{\partial \pi_1^a}{\partial p_2}\frac{\partial p_2}{\partial w} + x_2.$$

Differentiating once more with respect to w:

$$\begin{aligned} \frac{d^2\pi_1^a}{dw^2} &= \frac{\partial p_2}{\partial w}\left[\frac{\partial^2 \pi_1^a}{\partial p_2 \partial w} + \frac{\partial^2 \pi_1^a}{\partial p_2^2}\frac{\partial p_2}{\partial w} + \frac{\partial^2 \pi_1^a}{\partial p_2 \partial p_1}\frac{\partial p_1}{\partial w}\right] \\ &+ \frac{\partial^2 p_2}{\partial w^2}\frac{\partial \pi_1^a}{\partial p_2} + \frac{\partial x_2}{\partial p_1}\frac{\partial p_1}{\partial w} + \frac{\partial x_2}{\partial p_2}\frac{\partial p_2}{\partial w} < 0 \end{aligned}$$

Finally, note that

$$\frac{\partial \pi_1^a}{\partial w}|_{c_1} = (p_1 - c_1)\frac{\partial x_1}{\partial p_2} + x_2 > 0,$$

so that the optimal access charge is always higher than c_1. (Note that we do not rule out the fact that the profit function is always increasing in w, so that the optimal access charge is $w = \overline{p}$, resulting in no production for the entrant.)

Proof of Proposition 2: The argument is standard and hence omitted.

Proof of Lemma 2: Fix the marginal cost of firm 2 at x and consider the following profit functions:

$$\begin{aligned}\pi_1^h &= (p_1 - c_1)x_1(p_1,p_2) + \beta(x - c_1)x_2(p_1,p_2),\\ \pi_2^h &= (p_2 - x)x_2(p_1,p_2).\end{aligned}$$

If $\beta = 1$, this system corresponds to the profit functions under access ; if $\beta = 0$, it corresponds to bypass. Under Assumption 1, we can check that

$$\begin{aligned}\frac{\partial^2 \pi_1^h}{\partial p_1^2} &< -\tfrac{\partial^2 \pi_1^h}{\partial p_1 \partial p_2} < 0,\\ \frac{\partial^2 \pi_2^h}{\partial p_2^2} &< -\tfrac{\partial^2 \pi_1^h}{\partial p_1 \partial p_2} < 0\end{aligned}$$

Next compute the first order conditions characterizing the equilibrium prices:

$$x_1(p_1,p_2) + \frac{\partial x_1}{\partial p_1}(p_1 - c_1) + \beta\frac{\partial x_2}{\partial p_1}(x - c_1) = 0, \tag{15}$$

$$x_2(p_1,p_2) + \frac{\partial x_2}{\partial p_2}(p_2 - x) = 0. \tag{16}$$

By a standard computation,

$$\begin{aligned}\frac{\partial p_1}{\partial \beta} &= \frac{-\frac{\partial x_2}{\partial p_1}(x - c_1)\frac{\partial^2 \pi_1^a}{\partial p_2^2}}{E},\\ \frac{\partial p_2}{\partial \beta} &= \frac{\frac{\partial x_2}{\partial p_1}(x - c_1)\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}}{E},\end{aligned}$$

where

$$E = \frac{\partial^2 \pi_1^h}{\partial p_1^2}\frac{\partial^2 \pi_2^h}{\partial p_2^2} - \frac{\partial^2 \pi_1^h}{\partial p_1 \partial p_2}\frac{\partial^2 \pi_2^h}{\partial p_1 \partial p_2} > 0.$$

Hence, if $x < c_1$, $\frac{\partial p_1}{\partial \beta} < 0$ and $\frac{\partial p_2}{\partial \beta} < 0$; if $x > c_1$, $\frac{\partial p_1}{\partial \beta} > 0$ and $\frac{\partial p_2}{\partial \beta} > 0$ and if $x = c_1$, $\frac{\partial p_1}{\partial \beta} = \frac{\partial p_2}{\partial \beta} = 0$
Next note that

$$\begin{aligned}
\frac{\partial \pi_1^h}{\partial \beta} &= \frac{\partial \pi_1^h}{\partial p_2}\frac{\partial p_2}{\partial \beta} + (x - c_1)x_2, \\
&= (p_1 - c)\frac{\partial x_1}{\partial p_2}\frac{\partial p_2}{\partial \beta} + \beta(x_1 - c)\frac{\partial x_2}{\partial p_2}\frac{\partial p_2}{\partial \beta} + (x - c_1)x_2, \\
\frac{\partial \pi_2^h}{\partial \beta} &= \frac{\partial \pi_2^h}{\partial p_1}\frac{\partial p_1}{\partial \beta}, \\
&= (p_2 - x)\frac{\partial x_2}{\partial p_1}\frac{\partial p_1}{\partial \beta}.
\end{aligned}$$

Suppose first that $x < c_1$. Then, $\frac{\partial p_1}{\partial \beta} < 0$ and $\frac{\partial p_1}{\partial \beta} < 0$. As $x < p_2$ and $\frac{\partial x_2}{\partial p_1} > 0$, we immediately obtain $\frac{\partial \pi_2^h}{\partial \beta} < 0$, so that $\pi_2^a(x) < \pi_2^b(x)$. Now notice that

$$\begin{aligned}
(x_1 - c)\frac{\partial x_2}{\partial p_2}\frac{\partial p_2}{\partial \beta} &= \beta\frac{\partial x_2}{\partial p_2}(x - c_1)^2\frac{\partial x_2}{\partial p_1}\frac{\partial^2 \pi_1^a}{\partial p_1 \partial p_2}\frac{1}{E}, \\
&< 0.
\end{aligned}$$

so that,

$$\begin{aligned}
\frac{\partial \pi_1^h}{\partial \beta} &< (p_1 - c)\frac{\partial x_1}{\partial p_2}\frac{\partial p_2}{\partial \beta} + (x - c_1)x_2, \\
&< 0.
\end{aligned}$$

where the last inequality is obtained because $\frac{\partial p_2}{\partial \beta} < 0$, $\frac{\partial x_1}{\partial p_2} > 0$ and $x < c_1$. Hence, $\pi_1^a(x) < \pi_1^b(x)$.

Next, suppose that $w^* > x > c_1$, so that $\frac{\partial p_1}{\partial \beta} > 0$ and $\frac{\partial p_1}{\partial \beta} > 0$. We immediately obtain: $\frac{\partial p_2^h}{\partial \beta} > 0$ so that $\pi_2^a(x) > \pi_2^b(x)$. Next note that, as π_1^a is concave and $x < w^*$, $\frac{\partial \pi_1^a}{\partial w} > 0$, and

$$\frac{\partial \pi_1^a}{\partial w} = \frac{\partial p_2}{\partial w}((w-c_1)(\frac{\partial x_2}{\partial p_2} + (p_1-c_1)\frac{\partial x_1}{\partial p_2})) > 0.$$

By Proposition 1, $\frac{\partial p_2}{\partial w} > 0$, so that

$$(w-c_1)(\frac{\partial x_2}{\partial p_2} + (p_1-c_1)\frac{\partial x_1}{\partial p_2}) > 0,$$

and, as $\beta(x-c_1) < x - c_1$, we have that, for all $x < w^*$,

$$\begin{aligned}
\frac{\partial \pi_1^h}{\partial \beta} &= \frac{\partial p_2}{\partial \beta}((p_1-c)\frac{\partial x_1}{\partial p_2} + \beta(x_1-c)\frac{\partial x_2}{\partial p_2}) + (x-c_1)x_2, \\
&> (x-c_1)x_2, \\
&> 0.
\end{aligned}$$

so that $\pi_1^a(x) > \pi_1^b(x)$.

Proof of Proposition 4: We first show that, under Assumption 2, $\frac{\partial U}{\partial p_1} < 0$ and $\frac{\partial U}{\partial p_2} < 0$. To this end, notice that the maximization problem of the consumer results in the two equations:

$$\begin{aligned}
p_1 &= \frac{\partial U}{\partial x_1}, \\
p_2 &= \frac{\partial U}{\partial x_2},
\end{aligned}$$

which implicitly defines the demand functions $x_1(p_1, p_2)$ and $^x_2(p_1, p_2)$. Furthermore,

$$\begin{aligned}
\frac{\partial^2 U}{\partial x_1^2}\frac{dx_1}{dp_1} + \frac{\partial^2 U}{\partial x_1 \partial x_2}\frac{dx_2}{dp_1} &= 1, \\
\frac{\partial^2 U}{\partial x_1 \partial x_2}\frac{dx_1}{dp_1} + \frac{\partial^2 U}{\partial x_2^2}\frac{dx_2}{dp_1} &= 0.
\end{aligned}$$

so that

$$\frac{\partial x_2}{\partial p_1} = -\frac{\frac{\partial^2 U}{\partial x_1 \partial x_2}}{\frac{\partial^2 U}{\partial x_1^2}\frac{\partial^2 U}{\partial x_2^2} - \frac{\partial^2 U}{\partial x_1 \partial x_2}}. \tag{17}$$

Next, compute

$$\begin{aligned}
\frac{\partial U}{\partial p_1} &= \frac{\partial U}{\partial x_1}\frac{\partial x_1}{\partial p_1} + \frac{\partial U}{\partial x_2}\frac{\partial x_2}{\partial p_1} - x_1 + p_1\frac{\partial x_1}{\partial p_1}, \\
&= p_1\frac{\partial x_1}{\partial p_1} + \frac{\partial U}{\partial x_2}\frac{\partial x_2}{\partial p_1} - x_1 - p_1\frac{\partial x_1}{\partial p_1}, \\
&= \frac{\partial U}{\partial x_2}\partial x_2 \partial p_1 - x_1, \\
&< 0.
\end{aligned}$$

Where the last inequality stems from Assumption 2. A similar computation shows that $\frac{\partial U}{\partial p_2} < 0$, so that any increase in prices harms consumers.

By Lemma 2, if $x < c_1$, $\frac{\partial p_1}{\partial \beta} < 0$ and $\frac{\partial p_2}{\partial \beta} < 0$. Hence, $p_1^a(c_2) < p_1^b(c_2)$ and $p_2^a(c_2) < p_2^b(c_2)$ so that $U^a(c_2) > U^b(c_2)$. In addition, $\tilde{w}(c_2) < c_2$ and, by Proposition 1, $\frac{\partial p_1^a}{\partial w} > 0$ and $\frac{\partial p_2^a}{\partial w} > 0$ so that $p_1^a(\tilde{w}(c_2)) < p_1^a(c_2)$ and $p_2^a(\tilde{w}(c_2)) < p_2^a(c_2))$ showing that, $U^a(\tilde{w}(c_2)) > U^a(c_2) > U^b(c_2)$.

By the proof of Lemma 2, if $x > c_1$, $\frac{\partial p_1}{\partial \beta} > 0$ and $\frac{\partial p_2}{\partial \beta} > 0$, so that $p_1^a(c_2) < p_1^b(c_2)$ and $p_2^a(c_2) < p_2^b(c_2)$ and $U^b(c_2) > U^a(c_2)$. Suppose first that $\tilde{w}(c_2) < w^*$. Then, as $\tilde{w}(c_2) > c_2$, by Proposition 1, $p_1^a(\tilde{w}(c_2)) > p_1^a(c_2)$ and $p_2^a(\tilde{w}(c_2)) > p_2^a(c_2))$ showing that, $U^a(\tilde{w}(c_2)) < U^a(c_2) < U^b(c_2)$.

If now $\tilde{w}(c_2) > w^*$, then in order to deter bypass, the incumbent optimally selects $w = w^*$, and U^a is independent of c_2. If $c_2 < \overline{c}_2$, $U^b(c_2) > U^a(w^*)$ and if $c_2 > \overline{c}_2$, $U^b(c_2) < U^a(w^*)$.
Finally, notice that, as $w^* > c_1$, $U^a(w^*) < U^b(w^*)$ so that $\overline{c}_2 > w^*$.

Proof of Proposition 5: As the equilibrium of the pricing game and of the make-or-buy decision have been discussed in the text, we focus on the incumbent's access charge choice at the first stage of the game.

When $c_2 \geq c_1$, the argument underlying Proposition 3 remains valid, as $\pi_1^a(x) > \pi_1^b(x)$ and $\pi_2^a(x) > \pi_2^b(x) - f_2$ for all $x > c_1$. However, it is not necessarily the case that $\pi_2^b(x) - f_2 > \pi_2^a(x)$ for $x < c_1$, so that the analysis of the case $c_2 < c_1$ needs to be modified. Define $\bar{f}_2$ to be the fixed cost level such that the entrant is indifferent between access at w^* and bypass,

$$\tilde{w}(c_2, \bar{f}_2) = w^*,$$

and $\bar{\bar{f}}_2$ the fixed cost level at which the incumbent is indifferent between bypass and access:

$$\pi_1^a(\tilde{w}(c_2, \bar{\bar{f}}_2)) = \pi_1^b(c_2).$$

If $f_2 < \min\{\bar{f}_2, \bar{\bar{f}}_2\}$, then $\tilde{w}(c_2, \bar{f}_2) < w^*$ and the incumbent must select an access charge $\tilde{w}(c_2, f_2)$ to deter bypass, but deterring bypass is not profitable as $\pi_1^a(\tilde{w}(c_2, \bar{\bar{f}}_2)) \leq \pi_1^b(c_2)$. Hence, bypass will be chosen. On the other hand, if $f_2 \geq \min\{\bar{f}_2, \bar{\bar{f}}_2\}$, two cases arise. If $f_2 > \bar{f}_2$, the incumbent can deter access by choosing the optimal access charge w^*, which by a simple revealed preference argument, must result in a higher profit than bypass. If $\bar{f}_2 > f_2 > \bar{\bar{f}}_2$, the incumbent deters bypass by selecting a limit access charge $\tilde{w}(c_2, f_2)$ which results in a higher profit than bypass.

When $c_2 < c_1$, the incumbent has the choice between the limit access charge $\tilde{w}(c_2, f_2)$ or bypass. From equation (12), it is immediate that, for a given c_2, a higher fixed cost leads to a higher $\tilde{w}$. Furthermore, we know that $\tilde{w}(c_2, 0) < c_2$. Furthermore, let us define by $\bar{f}_2$, the fixed cost value such that the limit access charge is equal to w^*: $\pi_2^a(w^*) = \pi_2^b(c_2) - \bar{f}_2$ and we recall that $w^* > c_1$ (Lemma 1).

When the fixed cost is such that $\tilde{w}(c_2, f_2) \leq c_2 < c_1$, the incumbent is strictly better off allowing bypass. When the fixed cost is such that $\tilde{w} \geq c_1$, the incumbent is better of preventing bypass since (1) the opportunity cost of access is non-negative ($\tilde{w}(c_2, f_2) \geq c_1$) and (2) the entrant is less aggressive at the price setting stage ($\tilde{w}(c_2, f_2) > c_2$). By continuity, there exists a threshold value for the fixed cost such that, for the corresponding wholesale price level, the incumbent is indifferent between deterred bypass and allowed bypass.

Proof of Proposition 6: In the text.

Proof of Proposition 7: We first show that, given p_1 and w, the entrant chooses access if $w \leq c_2$ and bypass otherwise. The profit of the entrant can be expressed as $\pi_2 = (p_2 - x)x_2(p_1, p_2)$, where $x = c_2$ if the entrant bypasses and $x = w$ if the entrant buys access. Given that p_1 is already given at the second stage of the game, we observe by the envelope theorem that $\frac{\partial \pi_2}{\partial x} < 0$. Hence, the entrant selects the cheapest input price, and will bypass if $c_2 < w$ and buy access otherwise.

In order to deter bypass, the incumbent must price access at or below the entrant's marginal cost. As long as c_2 is smaller than w^{**}, it is the optimal limit access price is $w = c_2$. This strategy dominates accommodating bypass if and only if $c_2 \geq c_1$. Finally, if $c_2 > w^{**}$, the incumbent can deter bypass by selecting the optimal access charge w^{**}.